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CORROSION RATES IN SEA WATER AT PORT HUENEME, CALIFORNIA, FOR SIXTEEN METALS JULY 1951--JANUARY 1954.

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SUMMARY

Initial work on corrosion, after the location of the Naval Civil Engineering Research and Evaluation Laboratory at Port Hueneme, California, was the placing of various type metal panels into the sea water within the harbor in order to determine the severity of corrosion in this locality.

On 17 July 1951, five panels each of sixteen different metals were mounted on porcelain insulators in racks and placed in the harbor water for continuous immersion. At the end of each six-month period, one panel of each type metal was removed from the harbor, and the pitting and weight loss was determined. On 17 January 1954, the last (or fifth) panel of each metal was removed, and the corrosion losses were determined.

Compared with corrosion data found in reference 4, the results of this investigation (which continued over a period of thirty months) indicate no unusual corrosive conditions in this harbor.

CONTENTS

INTRODUCTION

A. Historical

These corrosion studies were part of Project[1] NY 450-004, dated 26 April 1951, which superceded Project[2] NY 450 04B, dated 15 September 1948. By reference to RDB Project Card[3], dated 1 July 1952, this study "was initiated to augment private industry's investigation in the field of corrosion and also to execute independent research on the corrosive effect of the atmosphere and of salt water under conditions encountered in the Naval Shore Establishment". The first phase of this investigation was to determine the corrosive potentialities encountered in the harbor at Port Hueneme.

B. List of Metals

To determine the corrosiveness of the sea water in this harbor, sixteen metals were placed on porcelain insulators, mounted in racks, and placed in complete immersion in the harbor at Port Hueneme, California. The sixteen metals studied are listed below.

(1) Aluminum, Alcoa, 3S 1/2 hard, Navy stock No. 47-A-642-805

(2) Aluminum, Alcoa, 52S 1/4 hard, " " " 47-A-622-208

(3) Aluminum, Alcoa, Alclad, 24S-t

(4) Aluminum, Alcoa, 2S-O, Navy Stock No. 47-A-380-137

(5) Magnesium Alloy, Dowmetal FS-1a

(6) Magnesium Alloy, Dowmetal MA

(7) Magnesium Alloy, Dowmetal FS-1h (hard rolled temper)

(8) Aluminum Bronze, Revere alloy 429 (soft)

(9) Stainless Steel, Cold rolled (18-8) Navy Stock No. 47-S-2788

(10) Copper, soft, Electrolytic, Navy Stock No. 47-C-765

(11) Naval Brass (soft), Navy Stock No. 47-B-1395

(12) Lead Sheet, 99.5% pure, Navy Stock No. 47-L-320

(13) Low Carbon Steel Sheet (pickled, full cold-rolled), Navy Stock No. 47-S-3149-10

(14) Phosphor Bronze, Revere Alloy 308, (Cold-rolled), No. 2 Hard (Cu 95%, Sn 5%)

(15) Monel annealed, Dull mild finish, Navy Stock No. 47-N-405-950

(16) Manganese Bronze, Revere Alloy 454, Cold Rolled, No. 1 Hard

PROCEDURE

Equipment

Test panels were cut from metal sheets to a size of 12 inches by 12 inches. Each type metal varied in thickness from one-eighth to three-sixteenths inches. The cutting was accomplished by use of a metal saw, and care was exercised in an attempt to prevent cold-working the edges, which could set up electrolytic corrosion at the edges.

Five identical test panels of each type metal were immersed at the same time. The panels were supported by corrosion-resistant racks made from stainless steel. The panels were insulated from each other and from the rack by means of porcelain insulators. The rack design is described in reference (4), pages 1067-69.

Exposure of Panels

The panels were placed in the harbor sea water on 17 July 1951. One panel of each type metal was examined after each six-month period, and the degree of corrosion determined as weight loss. These losses were then calculated to a uniform-loss basis as inches per year (ipy). Since pitting was the major factor in corrosion loss for some of the metals exposed in the harbor at Port Hueneme, the maximum and average pit depth was determined by using a penetrometer with a needle point. Small pin-point pits were not included in this average.

Test Conditions

The temperature of the harbor water varied from 58°F to 64°F. The salinity variation did not appear to be a corrosion factor. The velocity of the water in the area of the immersed test panels was calculated to be two-tenths feet per second maximum and diminishes to approximately zero during tide change.

Data Tabulation

(a) The enclosed photographs give a picture of the relative effects of the sea water on metal panels after varying periods of exposure in Port Hueneme Harbor. The chief value of the photo-

graphs is that the relative pitting of the various metals is shown. Certain da kened areas in the photographs are stains, which are due to marine rowths or electrolytic cleaning. The section of the panel illustrated is approximately one-half actual size.

(b) Tables

The corrosion losses are tabulated in two tables. Table I presents the corrosion loss in inches per year (ipy) calculated from loss in weight and assuming uniform corrosion loss over the surface of the metal panel. Table II presents the results of pitting and lists the maximum pit depth and the average pit depth of all deep pits. Pin-hole pits and very small pits were excluded from this average. As explained by accompanying notations, the figures in parentheses are not to be used in comparisons.

(c) Specific Test Results

A brief statement will follow concerning the appearance of each metal panel after having been cleaned (by wire brushing alone or by wire brushing and electrolytic descaling) and after having been weighed.

RESULTS

Specific

The following descriptions are based on examination of the panels which are illustrated in the photographs:

(1) Aluminum, Alcoa, 3S 1/2 hard, Navy Stock No. 47-A-642-805

The corrosion appears to be mostly due to pitting. The pits appear to increase in size and depth rather than in number as the time of exposure increased. The pits appeared at the break in the cathodic oxide coating on the surface of the panel which produced anodic areas. Note in the photographs how corrosion followed scratch lines through the aluminum oxide coating.

(2) Aluminum, Alcoa, 52S 1/4 hard, Navy Stock No. 47-A-622-208

At the end of six months the corrosion appeared as numerous small pin holes of approximately .005 inches in depth. A diver salvaged the thirty-month specimen from the harbor floor. This panel showed very little increase in size of pits except for several large pits, approximately .035 inches in depth, which appeared to be caused by contact with other objects on the harbor floor and were probably electrolytic. The results from these two panels indicate that this alloy has good corrosion resistance; however, the environmental conditions of the panel salvaged from the harbor floor with relation to the other panels in this series are unknown.

(3) Aluminum, Alcoa, Alclad 24S-t

This aluminum corroded the least of the four types tested. The pits which formed appeared to increase in area rather than in depth.

(4) Aluminum, Alcoa, 2S-O, Navy Stock No. 47-A-380-137

Corrosion attack produced many deep pits which grew progressively deeper with time. They apparently started with breaks or scratches in the cathodic oxide coating on the surface of the panel.

(5) Magnesium Alloy, Dowmetal FS-1a

At the end of only six months, holes were corroded completely through the metal panel. By the end of one year, the panels had diminished in size until they fell from the corrosion racks (see photographs).

(6) Magnesium Alloy, Dowmetal MA

At the end of six months, severe over-all surface corrosion was evident. After one year, large holes had been corroded through the panel, and after eighteen months, the panels fell from the racks.

(7) Magnesium Alloy, Dowmetal FS-1h (hard-rolled temper)

These results were similar to those for Dowmetal FS-1a (see (5) above).

(8) Aluminum Bronze, Revere Alloy 429 (soft)

The surface of all five panels showed only a very slight, smooth form of surface pitting which was not localized.

(9) Stainless Steel, Cold-rolled (18% Chronium, 8% Nickel, 0.08% max. Carbon), Navy Stock No. 47-S-2788

The corrosion of the stainless steel (18-8) was in the form of elongated pits running from the top edge downward (In a few instances, from the bottom upward). These elongated pits often ran partly below the surface and penetrated through to the opposite side. It is possible that iron, grains of sand, copper, magnesium, or some material in or about the corrosion rack induced this type of corrosion through contact. The thirty-month panel which was salvaged from the harbor floor showed the least attack of the five panels.

(10) Copper, soft, Electrolytic, Navy Stock No. 47-C-765

During the corrosion test period only an occasional small pit was found in these five copper panels. The corrosion losses

were confined almost entirely to the edges. This type of corrosion indicated differences in temper of the two sides of the metal edge. Although a saw was used to cut these panels, temper differences apparently were introduced. In such cases slight potential differences exist so that the harder portion may be corroded preferentially.

(11) Naval Brass, (soft), Navy Stock No. 47-B-1395

The corrosion was very slight and at a uniform rate, with no apparent pitting.

(12) Lead Sheet, 99.5% pure, Navy Stock No. 47-L-320

The corrosion attack on the lead was very mild and uniform, with no pitting in evidence.

(13) Low Carbon Steel Sheet (pickled, full cold-rolled), Navy Stock No. 47-S-3149-10

The corrosion attack on the iron panel was severe and general, with no localized attack or pitting.

(14) Phosphor Bronze, Revere Alloy 308, (Cold-rolled), No. 2 Hard (Cu 95%, Sn 5%)

Corrosion attack was very mild, with slight, very shallow pitting near the edges.

(15) Monel, Annealed, Dull mild finish, Navy Stock No. 47-N-405-950

Corrosion attack was mostly in the form of pits and at the edge. Except for these pits (which progressively got deeper), the surface remained smooth and apparently free from attack. Marine organisms may cause localized oxygen concentration cells which in turn cause pitting, especially in stagnant water.

(16) Manganese Bronze, Revere Alloy 454, Cold-rolled, No. 1 Hard

Corrosion was very mild and uniform.

General

The rate of corrosion in the harbor at Port Hueneme appears to be similar to that of normal sea water, aggravated to some extent by marine growth. In spite of the fact that the average rate of flow past the panel exposure area is low (the maximum rate calculated to be approximately 0.2 feet per second), there appear to be no unusual effects due to stagnation. Pitting losses were a major factor for aluminum, stainless steel, and monel. There were no evidences of harbor pollution.

CONSLUSIONS

Aluminum Panels

The Alcoa, Alclad 24S-t, appeared to suffer the smallest amount of corrosion attack of the aluminum group of metals. The following quotation from reference (4) gives a description of Alclad aluminum as a type of metallurgical protective coating:

"Alclad Alloys are duplex wrought products which have a core of one aluminum alloy and a coating of aluminum or another aluminum alloy. Generally, the core comprises 90% of the total thickness with a coating comprising about 5% of the thickness on each side. The coating is metallurgically bonded to the core over the entire area of contact--the coating alloys are selected so that they will be anodic to the core alloys in most natural environments. Thus the coating will electrolytically protect the core where it is exposed at cut edges, rivet holes, or at scratches."

Magnesium Panels

The magnesium metals corroded so fast as not to merit discussion.

Stainless Steel

Stainless steel (18% Chronium, 8% Nickel, and a maximum of 0.08% Carbon) evidenced attack by corrosion in the formation of elongated pits. These pits were typical of 18-8 stainless steel panels placed in complete immersion in slow-moving or stagnant sea water. Reference (4) indicates that in this type of pitting the anodic products (iron and other metal chlorides) apparently concentrate inside the pit as they form. These acidic concentrated solutions destroy the passivity of the stainless steel; enlarging the pit, they flow out and down the panel, destroying its passivity and producing the elongated pits. The literature recommends 2-4% molybdenum to lessen the corrosion attack by pitting.

Copper Panel

During the thirty-month, under-water exposure, copper corrosion was confined almost entirely to the edges and was attributed to the differences in temper at the edge caused by cutting the panels from sheet stock.

Brass and Bronze Panels

Naval Brass (Navy Stock No. 47-B-1395), Phosphor Bronze (Revere Alloy 308), and Manganese Bronze (Revere Alloy 454) corroded in a smooth, uniform manner. The corrosion rates for these metals in sea water were slightly less than average, being in the range of 0.001 ipy or less for the bronze and 0.0003 to 0.0004 ipy for brass.[4]

Lead Panel

Lead (Navy Stock No. 47-L-320) evidenced the least attack by corrosion during the thirty-month underwater exposure in the Port Hueneme Harbor.

Low Carbon Steel Panel

Low Carbon Steel (Navy Stock No. 47-S-3149-10), according to reference (4), has a range of corrosion rates from 0.001 ipy to 0.0077 ipy when exposed continuously in sea water. Thus, the harbor water at Port Hueneme attacks low carbon steel at a rapid rate, the average for thirty-month exposure being 0.0068 ipy, with initial rates as high as 0.0075 ipy.

Monel Panel

Monel Metal (Navy Stock No. 47-N-405-950) evidenced considerable pitting, especially under marine growth. Reference (4) indicates that, where marine organisms accumulate, pitting may result from the localized oxygen concentration cells formed on the surface of the metal. The photographs of the monel panels show the results of pitting apparently formed beneath marine organisms.

REFERENCES

1. BUDOCKS RDB Card NY 450 004 (Corrosion Studies), 26 April 1951.

2. BUDOCKS RDB Card NY 450 04B Corrosion Studies (Solomon Is., Md.), Report date 15 September 1948.

3. BUDOCKS RDB Card NY 450 004 (Corrosion Studies), 1 July 1952.

4. Herbert H. Uhlig, PhD, The Corrosion Handbook (1948), Published by John Wiley & Sons, Inc., New York.

TABLE I

NO.	METAL	NAVY STOCK NO.	LOSS IN INCHES PER YEAR (ipy)					
			6 MONTHS	12 MONTHS	18 MONTHS	24 MONTHS	30 MONTHS	AVERAGE
1	Aluminum Alcoa, 3S 1/2 Hard	47-A-642-805	.0018	.0013	.0009	.00075	.00066	.0011
2	Aluminum Alcoa, 52S 1/4 Hard	47-A-622-208	.00055	(1)			.00022 (3)	
3	Aluminum Alcoa, Alclad, 24S-T	24S-T	.00039	.00060	.00033	.00042	(1)	.00044
4	Aluminum Alcoa, 2S-O	47-A-380-137	.0011	.0010	.00066	.00055	.00048	.00076
5	Magnesium Alloy, Dowmetal FS-1A		.0437 (4)	.0364 (4)	(2)			
6	Magnesium Alloy, Dowmetal MA		.0208 (4)	.0311 (4)	.0398 (4)	(2)		
7	Magnesium Alloy, Dowmetal FS-1h (Hard-rolled temper)		.0452 (4)	.0228 (4)	(2)			
8	Aluminum Bronze, Revere Alloy, 429 (Soft)		.00071	.00044	.00033	.00023	(1)	.00042
9	Stainless Steel, Cold-rolled (18-8)	47-S-2788	.0012	.00045	.00041	.00027	.00021 (1)(3)	.00051
10	Copper, Soft, Electrolytic	47-C-765	.00071	.00065	.00060	.00055	(1)	.00063
11	Naval Brass (Soft)	47-B-1395	.0013	.0011	.0012	.0010	(1)	.0012
12	Lead Sheet, 99.5% Pure	47-L-320	.00018	.00019	.00013	.00014	.00022	.00017
13	Low Carbon Steel, (Pickled, full cold-rolled)	47-S-3149-10	.0075	.0073	.0050	.0058	.0083	.0068
14	Phosphor Bronze, Revere Alloy 308, (Cu 95% Sn 5%) (Cold-rolled) No. 2 hard		.00074	.0006	.00052	.00050	.00046	.00056
15	Monel, Annealed	47-N-405-950	.0010	.0005	.00043	.00047	(1)	.0006
16	Manganese Bronze, Revere Alloy 454, (Cold-rolled) No. 1 hard		.00094	.0011	.0011	.00097	.0011	.0010

(1) Rack failure; metal panel lost.
(2) Excessive corrosion caused loss of metal panel.
(3) Found by salvage diver after thirty-month exposure.
(4) Large holes corroded through the metal panel.

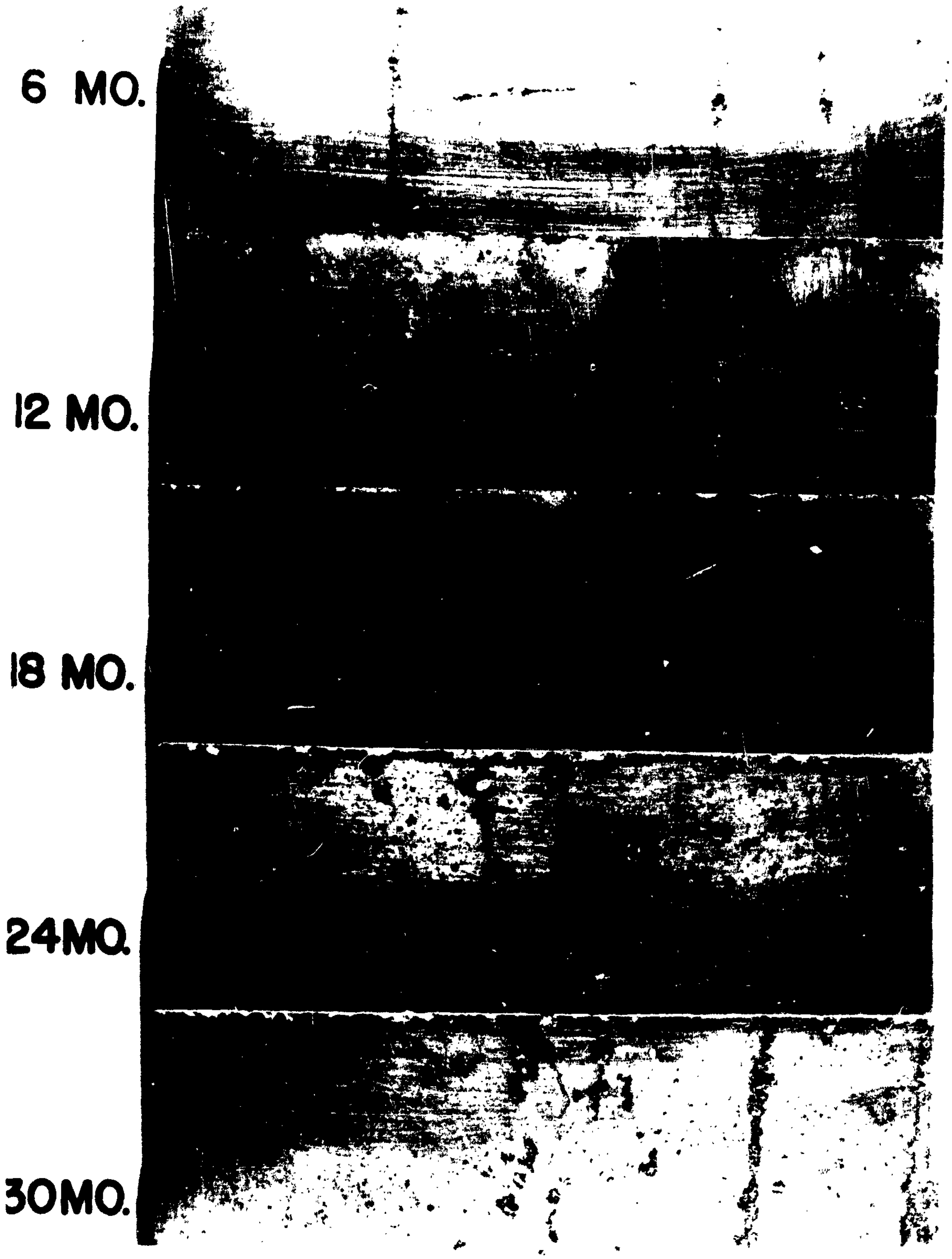
TABLE II

DEPTH OF PITS IN INCHES

METAL	6 MONTHS		12 MONTHS		18 MONTHS		24 MONTHS		30 MONTHS	
	Maximum	Average	Maximum	Average	Maximum	Average	Maximum	Average	Maximum	Average
Aluminum Alcoa, 3S 1/2 Hard	.0480	.0374	.0500	.0422	.0708	.0569	.0845	.0672	.0700	.0520
Aluminum Alcoa, 52S 1/4 Hard	(a)								.0457 (3)	.0347
Aluminum Alcoa, Alclad, 24S-T	(a)		.0040	.0039	.0049	.0035	.0065	.0044	(1)	
Aluminum Alcoa, 2S-O	.0220	.0190	.0320	.0270	.0462		.0540	.0526	.0700	.0438
Magnesium Alloy, Dowmetal FS-1A	(b)	0.1905	(b)	0.1905	(2)			(COMPLETE LOSS)		
Magnesium Alloy, Dowmetal MA	(c)	0.1945	(b)	0.1945	(b)	0.1945	(2)	(COMPLETE LOSS)		
Magnesium Alloy, Dowmetal FS-1h (Hard-rolled temper)	(b)	0.1834	(b)	0.1834	(2)			(COMPLETE LOSS)		
Aluminum Bronze, Revere Alloy 429 (Soft)		(d)		(d)		(d)		(d)	(1)	
Stainless Steel, Cold-rolled (18-8)	(b)(e)		(b)(e)		(b)(e)		(b)(e) (3½-inch long pit)		(e)(3)	
Copper, Soft, Electrolytic	(d)(f)		(d)(f)		(d)(f)		(d)(f)		(1)	
Naval Brass (Soft)	(d)		(d)		(d)		(d)		(1)	
Lead Sheet, 99.5% Pure	(d)		(d)		(d)		(d)		(d)	
Low Carbon Steel	(c)		(c)		(c)		(c)		(c)	
Phosphor Bronze, Revere Alloy 308	(d)		(d)		(d)		(d)		(d)	
Monel, Annealed	.0200	.0100	.0170	.0138	.0225	.0150	.0370	.0320	(1)	
Manganese Bronze, Revere Alloy 454	(d)		(d)		(d)		(d)		(d)	

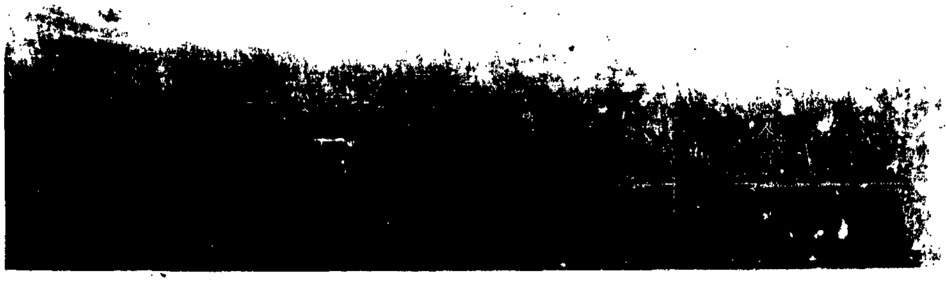
(a) Fine pin-point pitting covering surface of panel.
(b) Holes corroded through metal panels.
(c) Over-all pitting; continuous surface corrosion.
(d) No noticeable pitting.
(e) Elongated pits running vertically across panel.
(f) Corrosion confined to edges.

(1) Rack failure; metal panel lost.
(2) Excessive corrosion caused loss of metal panel.
(3) Found by salvage diver after thirty-month exposure.
(4) Large holes corroded through the metal panel.



1. ALUMINUM ALCOA 3S - 1/2 HARD; NAVY STOCK NO. 47-A-642-805

6 MO.



12 MO.

PANEL LOST

18 MO.

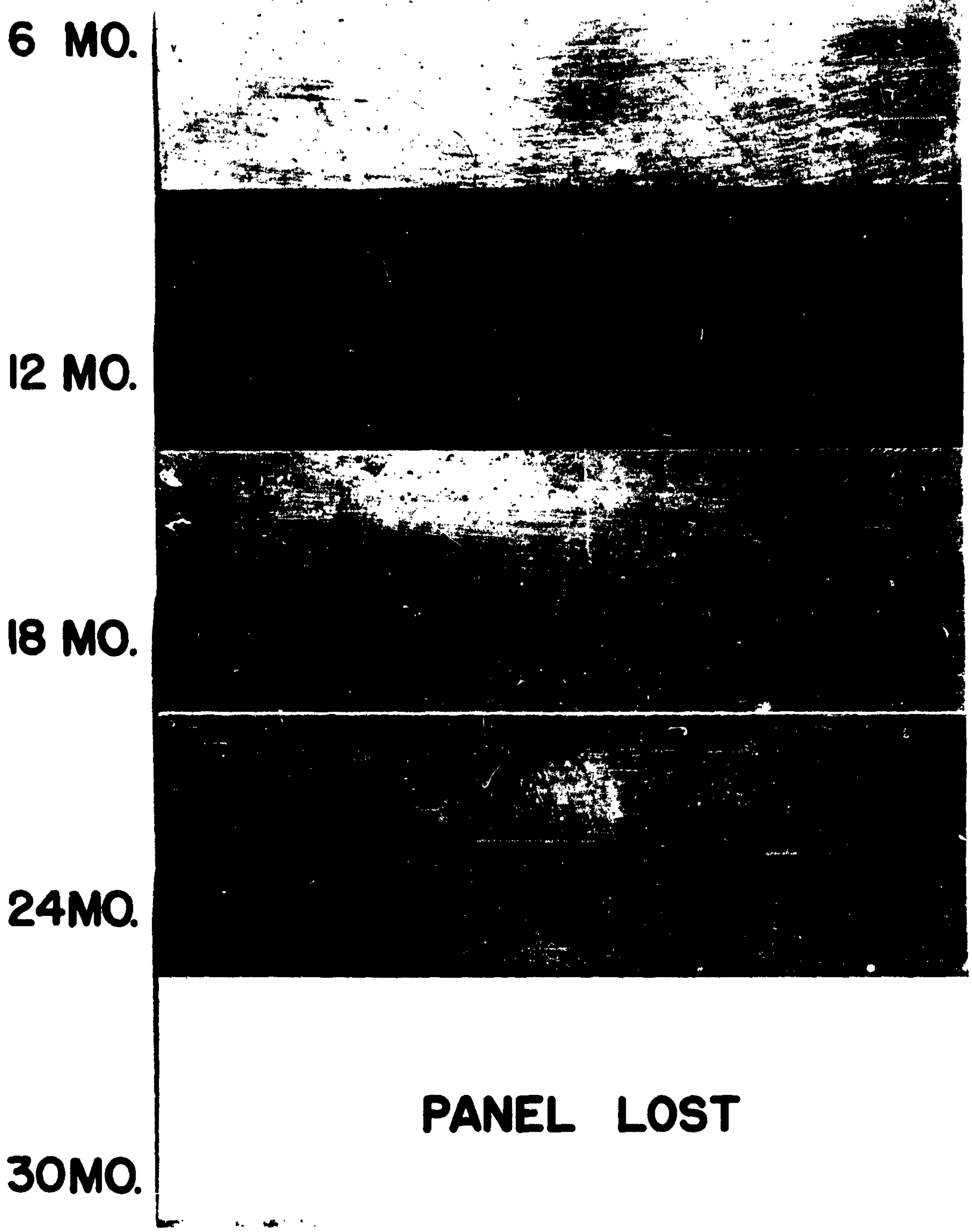
PANEL LOST

24MO.

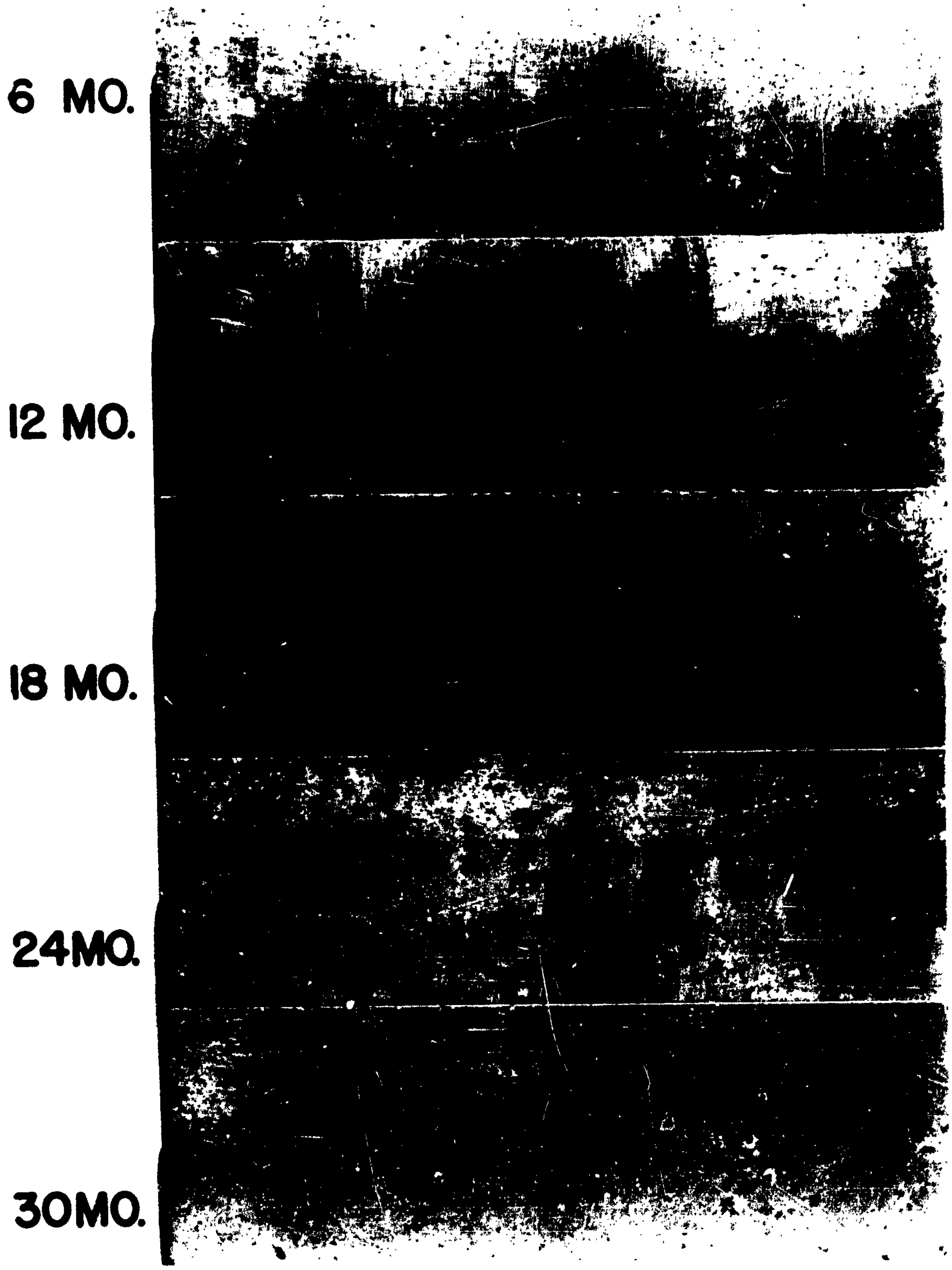
PANEL LOST

30MO.

2. ALUMINUM ALCOA 52-S 1/4 HARD; NAVY STOCK NO. 47-A-622-208

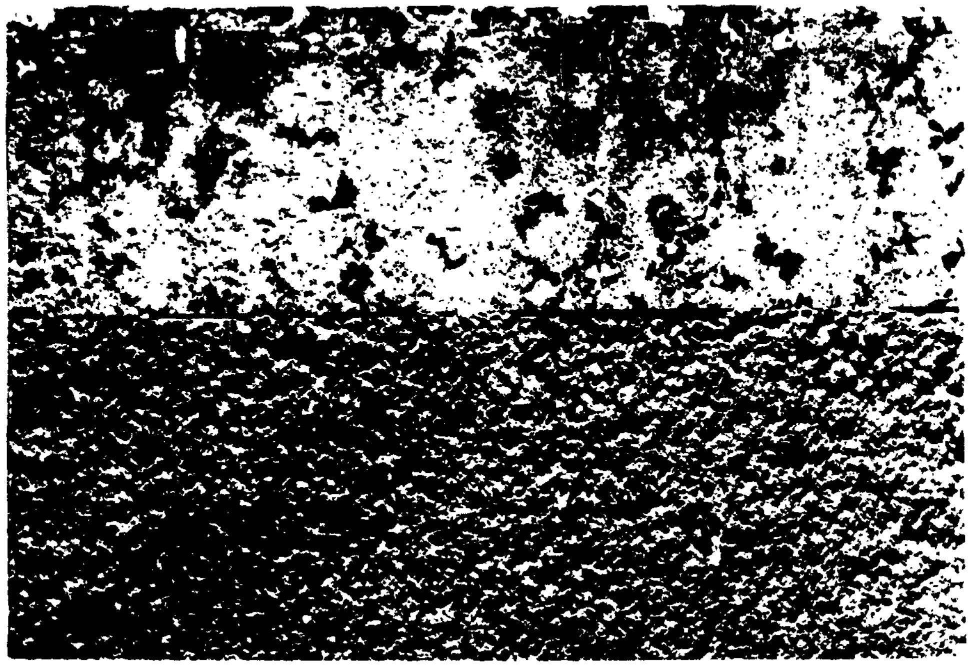


3. ALUMINUM ALCLAD 24S-T



4. ALUMINUM ALCOA 2S-0; NAVY STOCK NO. 47-A-380-137

6 MO.



12 MO.

CONSUMED BY
CORROSION

18 MO.

24MO.

CONSUMED BY
CORROSION

CONSUMED BY
CORROSION

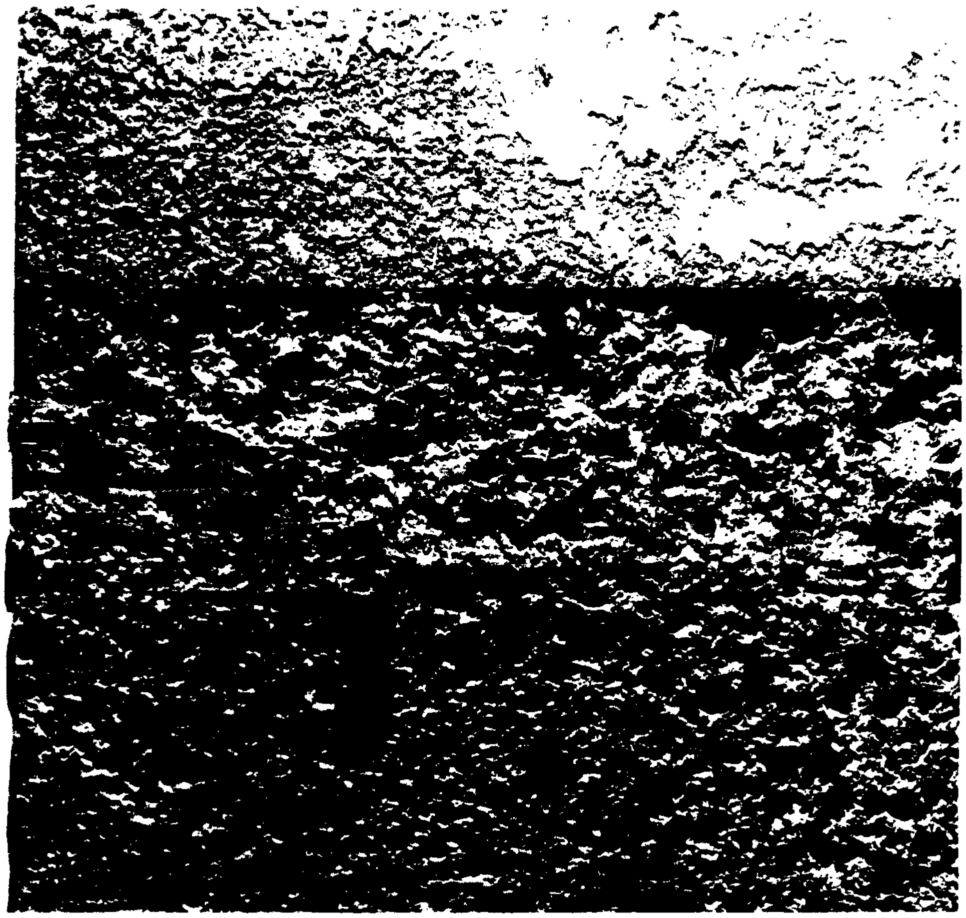
30MO.

5. MAGNESIUM ALLOY, DOWMETAL FS-1a

6 MO.

12 MO.

18 MO.



24MO.

CONSUMED BY
CORROSION

30MO.

CONSUMED BY
CORROSION

6. MAGNESIUM ALLOY, DOWMETAL MA

6 MO.

12 MO.

18 MO.

CONSUMED BY
CORROSION

24MO.

CONSUMED BY
CORROSION

30MO.

CONSUMED BY
CORROSION

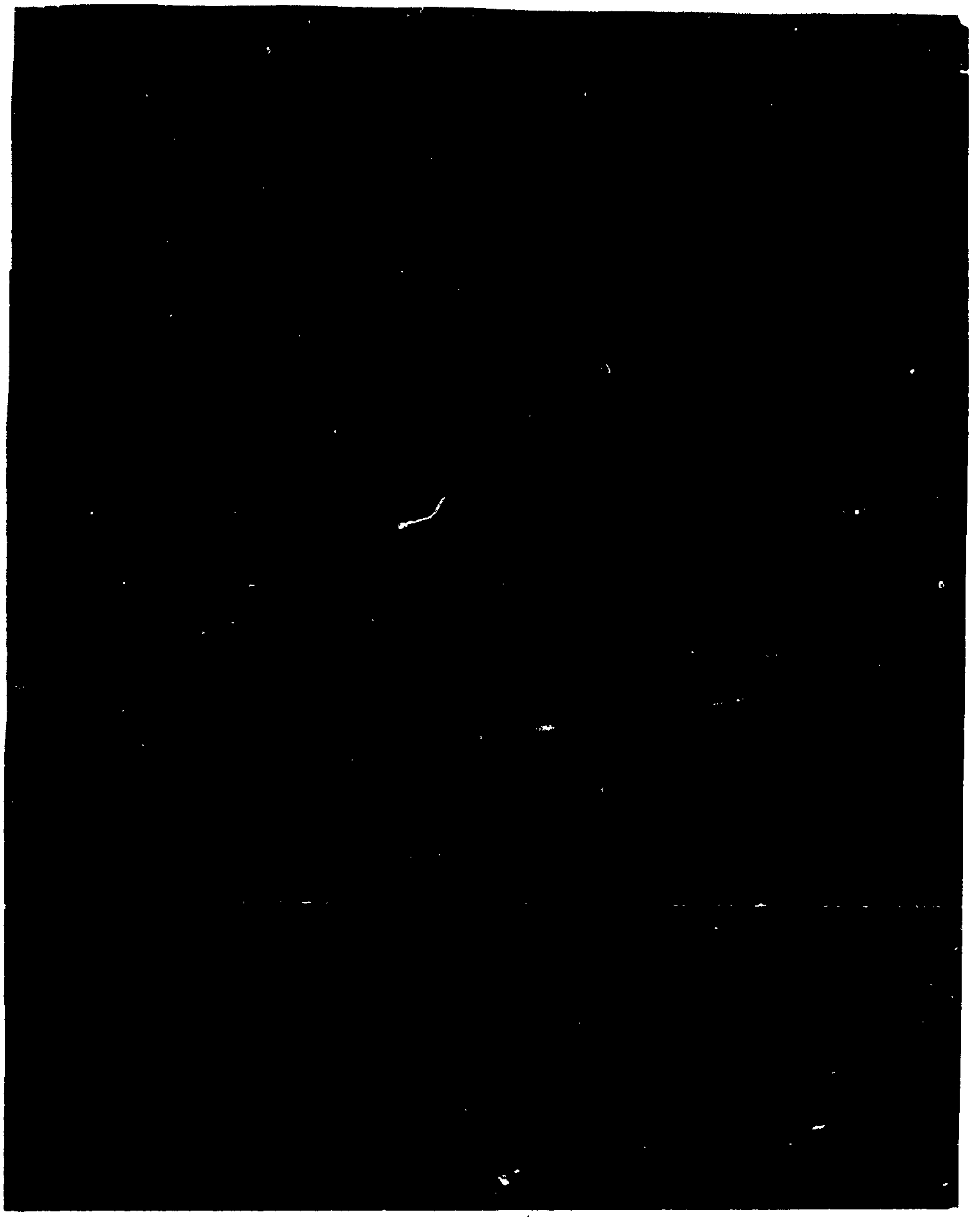
7. MAGNESIUM ALLOY, DOWMETAL FS-1h (HARD ROLLED TEMPER)

6 MO.

12 MO.

18 MO.

24MO.



PANEL LOST

30MO.

8. ALUMINUM BRONZE, REVERE ALLOY 429 (SOFT)

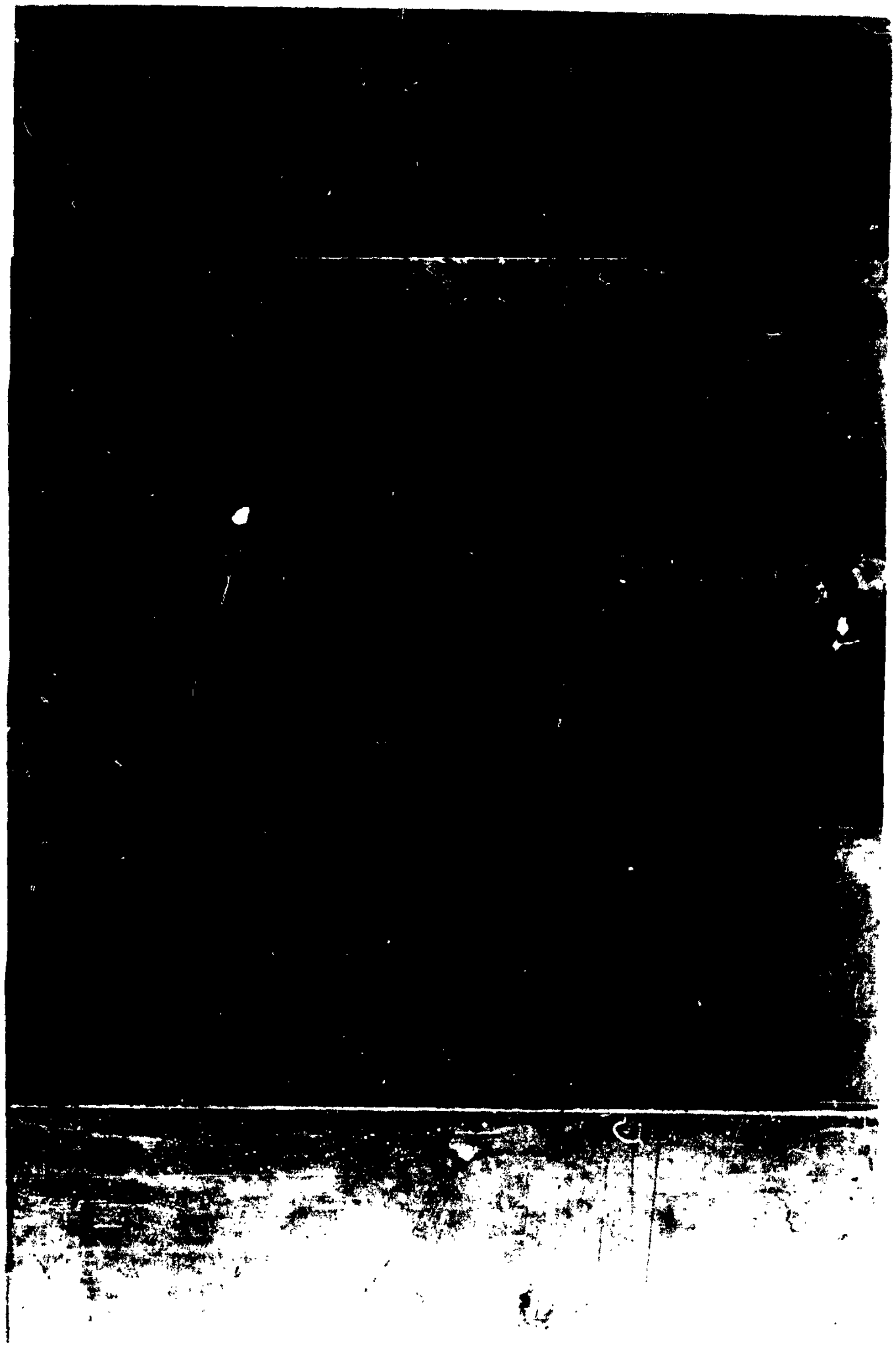
6 MO.

12 MO.

18 MO.

24MO.

30MO.



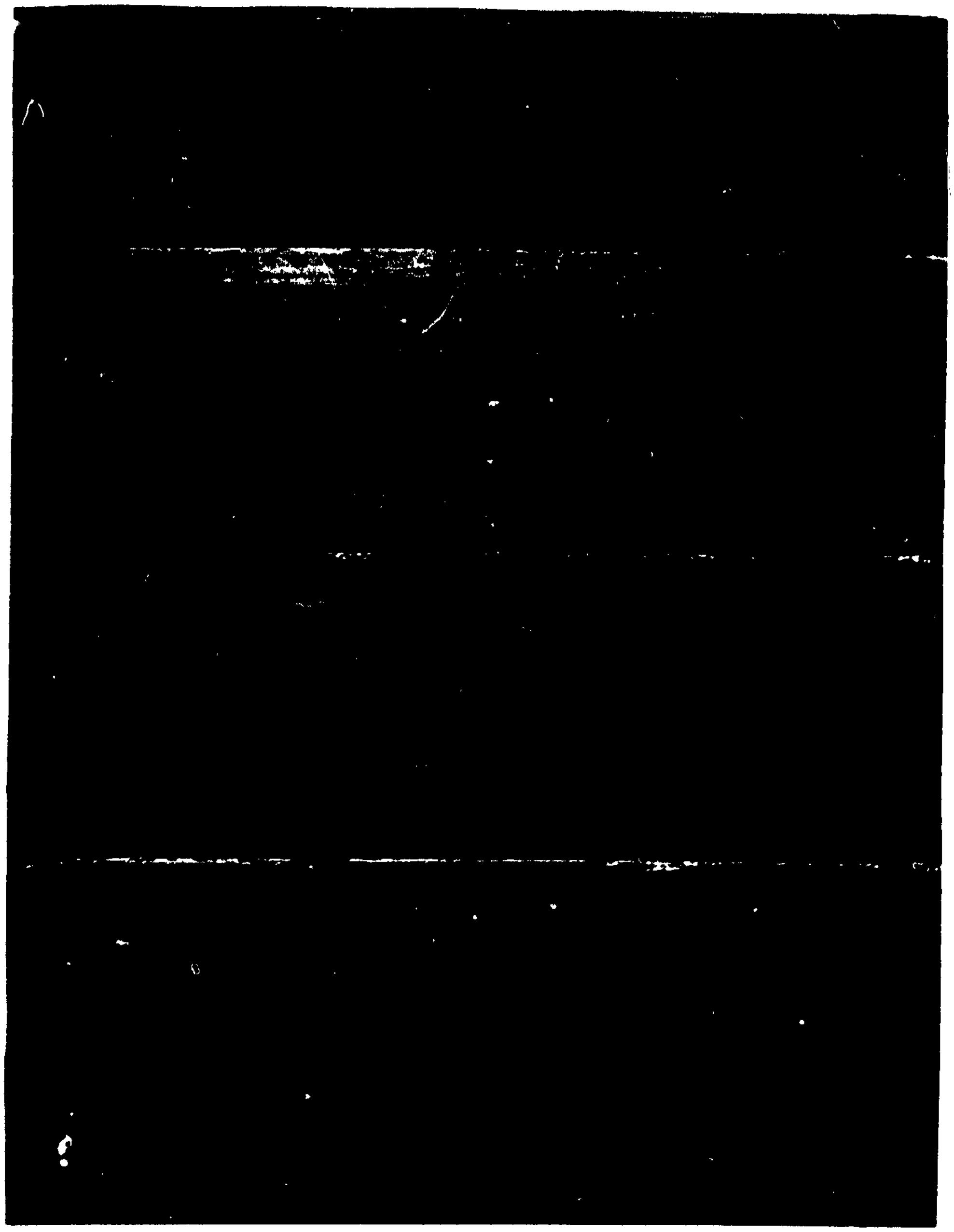
9. STAINLESS STEEL, COLD ROLLED (18-8); NAVY STOCK NO. 47-S-2788

6 MO.

12 MO.

18 MO.

24MO.



30MO. PANEL LOST

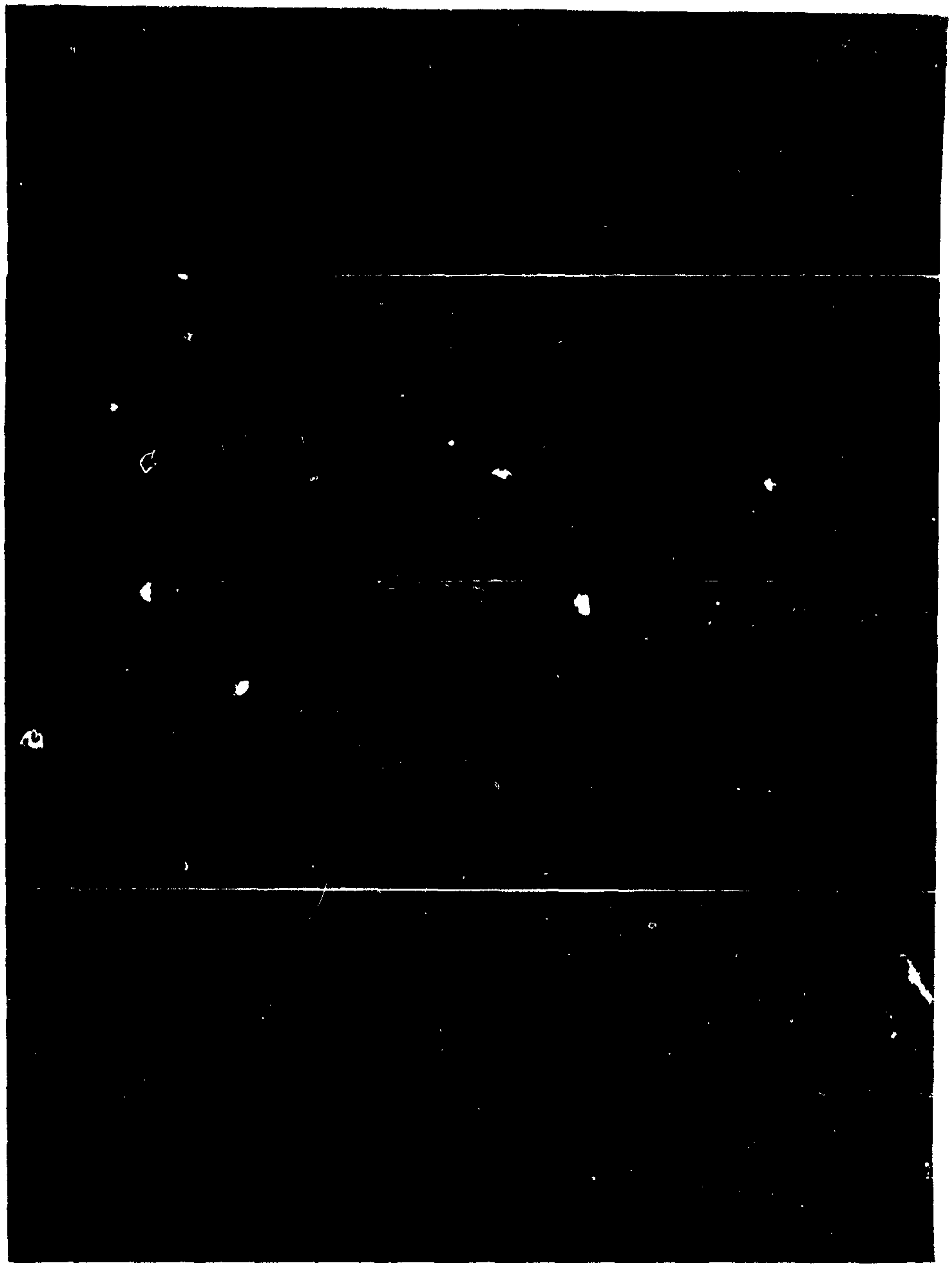
10. COPPER, SOFT, ELECTROLYTIC; NAVY STOCK NO. 47-C-765

6 MO.

12 MO.

18 MO.

24MO.



30MO. PANEL LOST

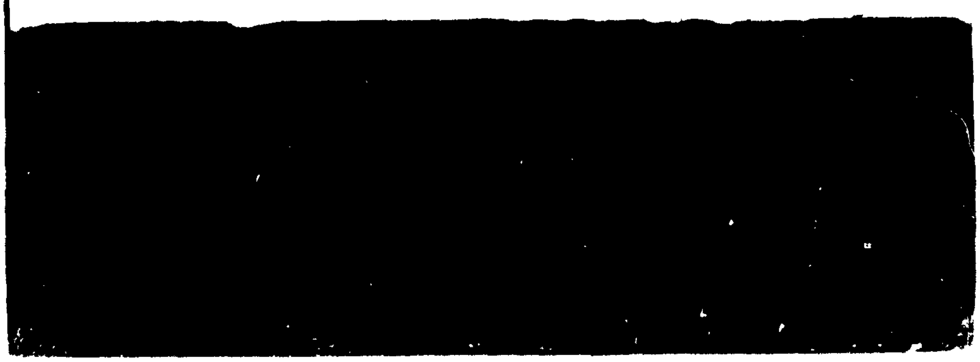
11. NAVAL BRASS, SOFT; NAVY STOCK NO. 47-B-1395

6 MO. PANEL LOST

12 MO.

18 MO.

24MO. PANEL LOST



30MO.

12. LEAD SHEET, 99.5% PURE; NAVY STOCK NO. 47-L-320

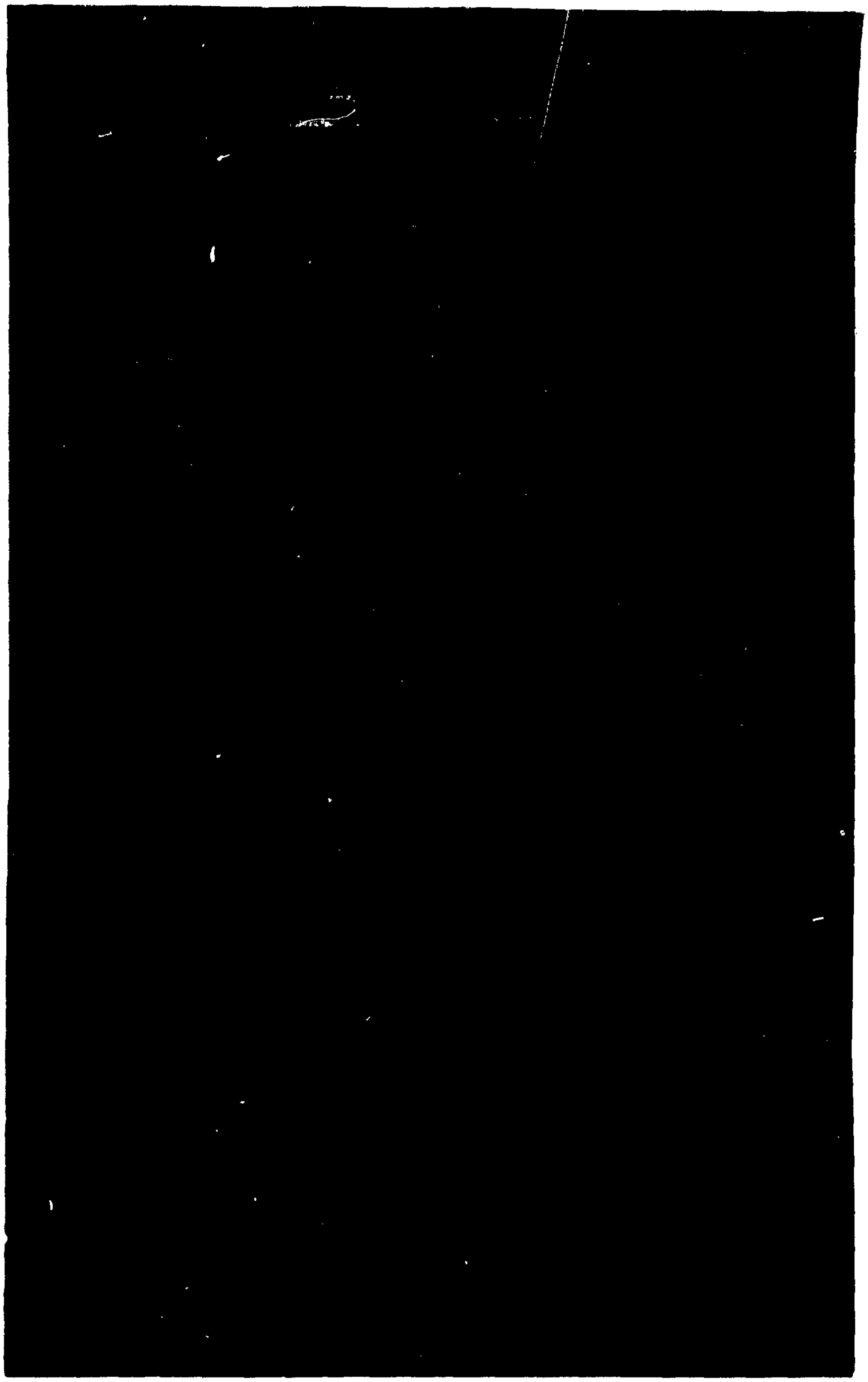
6 MO.

12 MO.

18 MO.

24MO.

30MO.



13. STEEL, LOW CARBON, SHEET, (PICKLED, FULL COLD ROLLED); NAVY STOCK NO. 47-S-3149-10

6 MO.

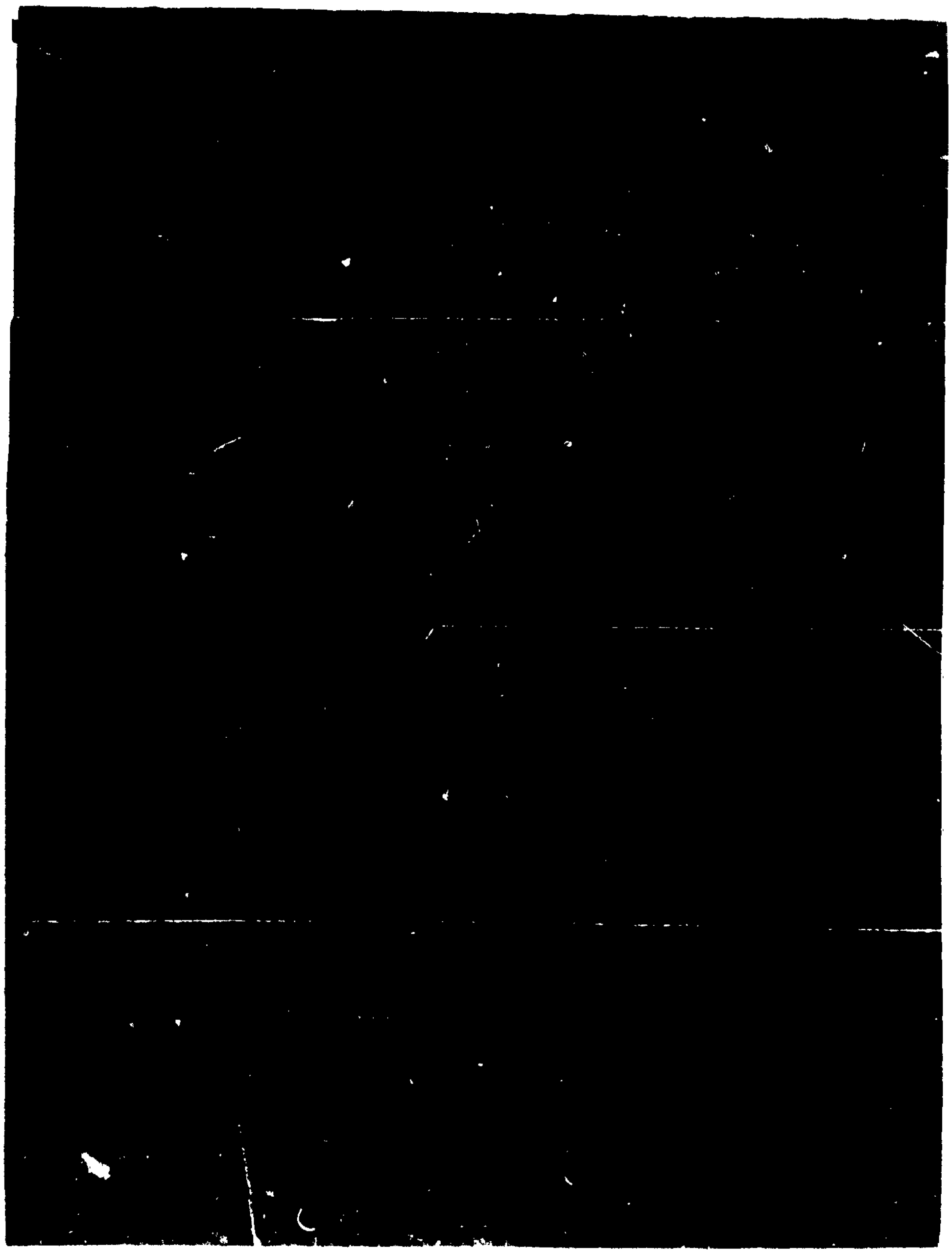
PANEL LOST

12 MO.

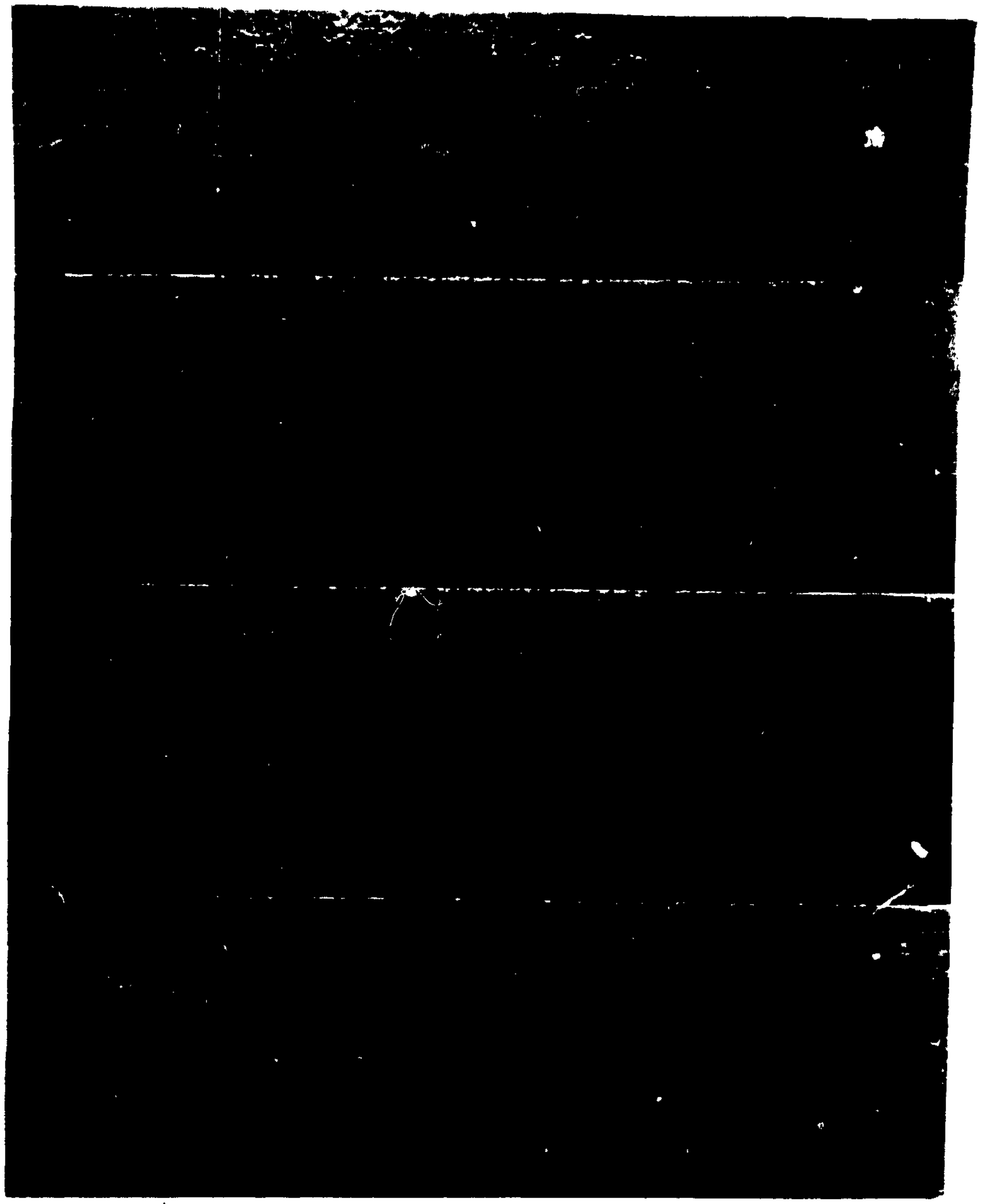
18 MO.

24MO.

30MO.



14. PHOSPHOR BRONZE, REVERE ALLOY 308, COLD ROLLED, NO. 2 HARD (95% Cu-5% Sn)



6 MO.

12 MO.

18 MO.

24MO.

PANEL LOST

30MO.

15. MONEL, ANNEALED, DULL MILD FINISH; NAVY STOCK NO. 47-N-405-950

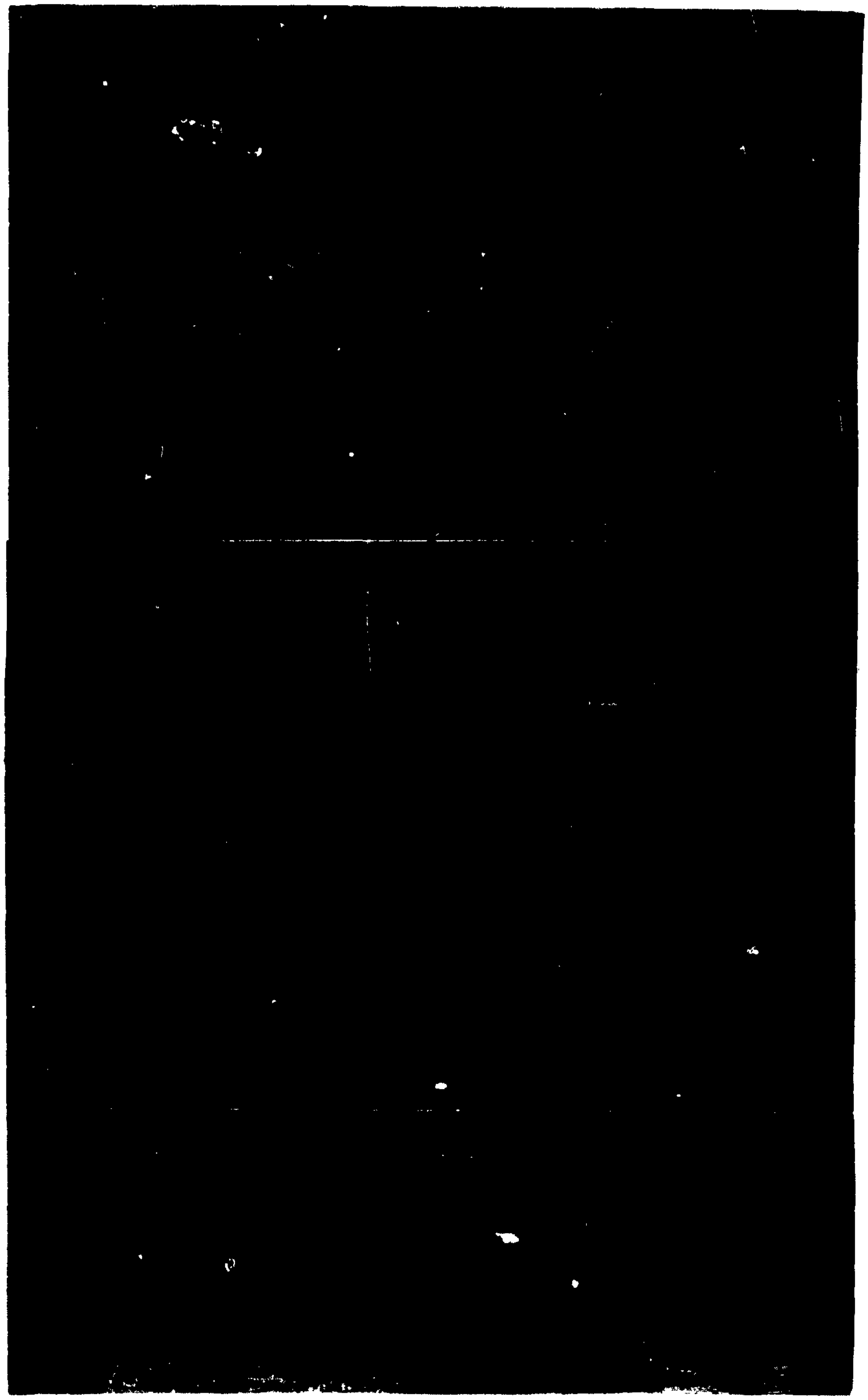
6 MO.

12 MO.

18 MO.

24MO.

30MO.



16. MANGANESE BRONZE, REVERE ALLOY 454, COLD ROLLED, NO. 1 HARD